U. S. NAVAL SUBMARINE MEDICAL CENTER

Submarine Base, Groton, Conn.

REPORT NUMBER 554

OBSERVATIONS OF INTRA-OCULAR PRESSURE CHANGES DURING AN FBM PATROL AS MEASURED BY SCHIOTZ TONOMETRY

by

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MR011.01-5012.01

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SUMMARY PAGE

THE PROBLEM

To determine whether a hazardous increase in intra-ocular pressure occurs as a result of elevated carbon dioxide levels in the atmosphere during Fleet Ballistic Missile (FBM) submarine patrols.

FINDINGS

Baseline ocular tensions were taken on 16 volunteers. Serial determinations were taken at weekly intervals on these same volunteers during an FBM patrol. No significant elevation above the baseline values was found in this group.

APPLICATIONS

These results can serve to reassure those responsible for the health of submarine crews that increased intra-ocular pressure is not a hazard attendant on prolonged submergence.

ADMINISTRATIVE INFORMATION

This report was prepared by the author in partial fulfillment of the requirements for qualification as a Submarine Medical Officer. It was approved for publication as Report No. 1 on In-House Research Work Unit MR011.01-5012, under date of 21 October 1968, in order that copies might be available in the School of Submarine Medicine and in the Technical Library, Submarine Medical Center, for study and reference purposes for students of submarine medicine.

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ABSTRACT

This paper discusses the method of establishing that no hazard of increased intra-ocular pressure is incurred from the elevated carbon dioxide content of the sealed submarine atmosphere. The reasons for suspecting a possible intra-ocular pressure rise under such conditions are presented. The serial tonometry readings, both under control conditions and at elevated ambient carbon dioxide levels while on patrol are shown. The conclusion from this study is that no elevation of intra-ocular pressure accompanies physiologic adjustments to high carbon dioxide levels.

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OBSERVATIONS OF INTRA-OCULAR PRESSURE CHANGES DURING AN FBM PATROL AS MEASURED BY SCHIÖTZ TONOMETRY

INTRODUCTION

The development of equipment able to artificially produce oxygen, and remove carbon dioxide and carbon monoxide from the atmosphere enables nuclear submarines to remain submerged for periods far in excess of those previously feasible. The use of this equipment has meant that submariners can and do live in a truly closed atmosphere environment. This has presented a most complex problem to those involved in caring for the health of submarine personnel, i.e., what levels of atmospheric constituents and contaminants, in a closed environment, can be tolerated by the human organism, without serious pathophysiologic effects? Because of the large number of gases and particulate substances involved, and the large number of possible physiologic effects, study and revision of the acceptable limits of atmospheric constituents is a continuous process.

The subject of this report is one possible pathophysiologic effect of elevated carbon dioxide concentrations in the submarine atmosphere. Schaefer, et al[1,3] have demonstrated that an uncompensated respiratory acidosis occurs in those exposed to an atmosphere with 1.5 percent carbon dioxide continuously for a period of six weeks. It can be concluded from these studies that the ambient level of carbon dioxide has a direct effect on the bicarbonate-carbonic acid plasma buffering system. Therefore, it would seem advisable to study those organ systems whose function is tied up with the bicarbonate-carbonic acid buffering system, for the purpose of determining whether any detrimental changes in their function occur.

The formation and absorption of aqueous humor,* in the posterior and anterior chambers of the eye, respectively, are functions which appear to be related to the bicarbonate-carbonic acid buffer system. While the mechanism of aqueous formation is not fully understood,[5,6] it appears that a combination of secretion and filtration is involved. It is known that the anion bicarbonate is present in lower concentrations in aqueous than in plasma,[6] and that the total CO_2 in aqueous is 63 volumes percent while the level in plasma is 55 to 75 volumes percent.[4]

In trying to understand the possible relationship between carbon dioxide and intra-ocular pressure, it is well to examine equation 1:

$$(1)\quad H_2O + CO_2 \overset{a}{\rightleftharpoons} H_2CO_3 \overset{b}{\rightleftharpoons} H^+ + HCO_3^-$$

Reaction (a) proceeds slowly in the absence of a catalyst, while reaction (b) proceeds very rapidly.[9] However, when the enzyme carbonic anhydrase is added to reaction (a), it will increase the speed of the reaction one hundredfold. Two phenomena of interest occur when an inhibitor of carbonic anhydrase (CA), such as acetazolamide, is administered to a patient. First, reaction (a) is greatly slowed, as in equation 2:

$$(2)\quad H_2O + CO_2 \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Second, intra-ocular pressure is reduced, through decreased aqueous formation. This would lead us to believe either equation 3 or equation 4 contributes to the formation of aqueous, and that interfering with one reaction or the other is what causes the decrease in aqueous formation.

$$(3)\quad H_2O + CO_2 \xrightarrow{CA^*} H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

$$(4)\quad H^+ + HCO_3^- \longrightarrow H_2CO_3 \xrightarrow{CA} H_2O + CO_2$$

Proceeding from that point, if we increase

*Wherever the word aqueous occurs subsequently in this report it is to be understood that aqueous humor is meant.

*carbonic anhydrase = CA

the alveolar pCO_2 we will drive equation 1 to the right, a situation which must be found in carbonic anhydrase containing tissues during the period of adaptation to elevated carbon dioxide levels, such as submarine patrols. It is logical that if reaction 3 is the reaction which aids in the formation of aqueous, an increase in ambient pCO_2 will tend to cause more aqueous to form and the intra-ocular pressure to increase. If, on the other hand, reaction 4 tends to produce aqueous, an increase in ambient pCO_2 will slow the reaction and decrease both aqueous formation and intra-ocular pressure. To repeat, one of these two must logically be the case from the information already presented.

Based on this single factor, the intra-ocular pressure would seem not to remain the same during a submarine patrol, but would either increase or decrease. The change, however, might be so small that it would not be detectable by ordinary methods, or it might be neutralized or overriden by other factors concurrently affecting intra-ocular pressure. The magnitude of change must be arrived at empirically.

In any case it would appear to be in the interest of submariners to make certain that the elevated levels of carbon dioxide in nuclear submarine atmospheres during prolonged submergence does not elevate intra-ocular pressure to a dangerous level. The purpose of this paper is to report on Schiotz tonometry done on sixteen volunteers during one patrol aboard the USS ROBERT E. LEE (SSBN 601), with the express purpose of examining for this phenomenon.

In order to keep this paper unclassified, no specific percentages of carbon dioxide in the atmosphere will be given. Those for whom this report is primarily intended will be familiar with the atmosphere control equipment on board FBM submarines[7,8] and will be aware of the carbon dioxide partial pressures ordinarily encountered. The partial pressures during the patrol in question differed in no major respect from the norm. It is the opinion of this author that revealing day to day and hour to hour carbon dioxide partial pressures would add little to inquiry on this study's primary question. It can, however, be stated that while daily variation did occur in the partial pressure of carbon dioxide, no trend in these values was discernable.

MATERIALS AND METHODS

A standardized and certified Schiotz tonometer was used for the measurements of intra-ocular pressure. Two drops of 0.5% tetracaine solution provided sufficient anesthesia for the procedure. Care was, of course, taken to disinfect the tonometer between patients. No morbidity arose from the procedure.

Sixteen volunteers, ranging in age from 21 to 35 were recruited from among the submarine crew. None of these volunteers had a history of serious eye disease, although two had a family history of glaucoma. R.G.'s father had glaucoma, controlled with the use of miotics. M.W.M.'s father had glaucoma which remained in remission following an iridectomy. No other members of either family have been similarly afflicted. Three, and in some cases four, baseline tonometry readings were taken on each volunteer, while in the normal ambient carbon dioxide level of 0.04%. Subsequently tonometry was done at weekly intervals, corresponding to the end of each week spent in the high carbon dioxide atmosphere.

The advantage of this method is that each subject served as his own control. His readings during the experimental period could be compared with his readings during normal carbon dioxide levels. Each eye is considered individually, since each is essentially a separate physiologic unit.

RESULTS

Three or four control ocular tensions were recorded for each volunteer. The observations were made at weekly intervals. The findings are recorded in millimeters of mercury pressure in Table A. The mean values and standard deviations are significant only for the first, second, and fourth weeks, when all volunteers were observed. These values

were 18.6 ± 3.7 mm Hg, 19.8 ± 3.6 mm Hg, and 19.4 ± 3.7 mm Hg for the first, second, and fourth weeks respectively. The mean for all values taken on the three occasions was 19.3 ± 3.6 mm Hg.

TABLE A — BASELINE OCULAR TENSIONS

Week		1	2	3	4	Av.
L.B.	O.D.	16.9	18.5		21.8	19.1
	O.S.	20.1	20.1		21.8	20.7
W.B.	O.D.	15.6	20.1		23.4	19.7
	O.S.	15.6	21.8		18.5	18.6
O.C.	O.D.	18.5	18.5		18.5	18.5
	O.S.	20.1	14.2		18.5	17.6
R.C.	O.D.	14.2	18.5	15.6	18.5	16.7
	O.S.	14.2	18.5	14.2	16.9	15.9
E.F.	O.D.	20.1	16.9	15.6	18.5	17.8
	O.S.	18.5	18.5	13.2	18.5	17.2
R.G.	O.D.	16.9	18.5		21.8	19.1
	O.S.	16.9	18.5		25.4	20.3
L.L.	O.D.	23.4	20.1	18.5	20.1	20.5
	O.S.	18.5	20.1	18.5	20.1	19.3
F.L.	O.D.	16.9	18.5	21.8	21.8	19.8
	O.S.	16.9	18.5	21.8	21.8	19.8
B.D.M.	O.D.	13.2	14.2	11.9	11.9	12.8
	O.S.	14.2	14.2	11.0	11.9	12.8
B.W.M.	O.D.	16.9	25.4		25.4	22.6
	O.S.	25.4	25.4		25.4	25.4
E.P.	O.D.	21.8	25.4	18.5	16.9	20.7
	O.S.	15.6	20.1	18.5	15.6	17.5
R.P.	O.D.	15.6	18.5	15.6	15.6	16.3
	O.S.	15.6	16.9	15.6	13.2	15.3
R.S.	O.D.	26.5	25.4	23.4	21.8	24.3
	O.S.	26.5	25.4	25.4	23.4	25.2
J.V.	O.D.	21.8	21.8	25.4	18.5	21.9
	O.S.	23.4	18.5	21.8	23.4	21.8
B.N.	O.D.	15.6	20.1	13.2	14.2	15.8
	O.S.	15.6	20.1	15.6	16.9	17.1
J.B.	O.D.	20.1	18.5	20.1	18.5	19.3
	O.S.	23.4	23.4	20.1	21.8	22.2

The mean control intra-ocular pressure for each eye is also recorded in the right hand column of Table A. A histogram of the distribution of the latter values is shown in Figure 1. The distribution is roughly a gaussian curve. The mean is coincident with the mean value for the population as a whole.

Table B presents the intra-ocular pressures found in the same individuals during a submarine patrol. In this table, the value for week one is the ocular tension observed at the end of the first week of exposure to elevated carbon dioxide levels, the value for week two the end of the second week, etc. The mean values for all observations are as follows: week one 19.0 ± 4.1 mm Hg, week two 18.5 ± 3.4 mm Hg, week three 18.0 ± 3.6 mm Hg, week four 17.6 ± 4.3 mm Hg, week five 17.9 ± 4.0 mm Hg, week six 18.0 ± 4.4 mm Hg. These values are graphically represented in Figure 2.

TABLE B — OCULAR TENSIONS DURING PATROL

Week		1	2	3	4	5	6
L.B.	O.D.	23.4	23.4	20.1	20.1	20.1	20.1
	O.S.	23.4	23.4	18.5	20.1	20.1	20.1
W.B.	O.D.	23.4	21.8	21.8	20.1	20.1	20.1
	O.S.	20.1	18.5	15.6	18.5	23.4	21.8
O.C.	O.D.	18.5	20.1	21.8	16.9	16.9	20.1
	O.S.	13.2	18.5	18.5	14.2	16.9	18.5
R.C.	O.D.	14.2	14.2	14.2	14.2	16.9	13.2
	O.S.	14.2	13.2	15.6	11.9	16.9	20.1
E.F.	O.D.	16.9	16.9	18.5	11.9	13.2	9.0
	O.S.	18.5	14.2	16.9	13.2	15.6	11.0
R.G.	O.D.	20.1	18.5	18.5	15.6	20.1	20.1
	O.S.	20.1	18.5	18.5	15.6	20.1	18.5
L.L.	O.D.	20.1	20.1	16.9	15.6	14.2	15.6
	O.S.	20.1	20.1	16.9	16.9	14.2	15.6
F.L.	O.D.	20.1	15.6	20.1	15.6	16.9	20.1
	O.S.	20.1	15.6	16.9	16.9	13.2	18.5
B.D.M.	O.D.	14.2	13.2	13.2	14.2	11.0	11.0
	O.S.	14.2	13.2	13.2	11.9	13.2	11.0
B.W.M.	O.D.	30.3	20.1	30.3	28.3	30.3	23.0
	O.S.	26.5	16.9	26.5	26.5	23.0	26.5
E.P.	O.D.	18.5	23.4	18.5	21.8	16.9	20.1
	O.S.	16.9	21.8	15.6	18.5	20.1	21.8
R.P.	O.D.	14.2	15.6	15.6	14.2	14.2	14.2
	O.S.	15.6	13.2	14.2	14.2	14.2	11.9
R.S.	O.D.	23.4	23.4	18.5	25.4	15.6	21.8
	O.S.	21.8	23.4	18.5	21.8	16.9	18.5
J.V.	O.D.	20.1	21.8	15.6	20.1	20.1	20.1
	O.S.	20.1	21.8	16.9	21.8	21.8	25.4
B.N.	O.D.	13.2	15.6	15.6	14.2	14.2	14.2
	O.S.	13.2	16.9	15.6	13.2	15.6	11.9
J.B.	O.D.	20.1	18.5	18.5	20.1	23.4	20.1
	O.S.	20.1	20.1	21.8	20.1	21.8	20.1

DISCUSSION

In the analysis of the data here presented, it is necessary to examine both the group of volunteers as a whole, and each individual. This is necessary in order to ascertain not only that no hazard exists for submarine personnel as a group, but also that no hazard

exists to special classifications of submariners. Particularly of interest are those with high normal intra-ocular pressures, and those with a family history of glaucoma.

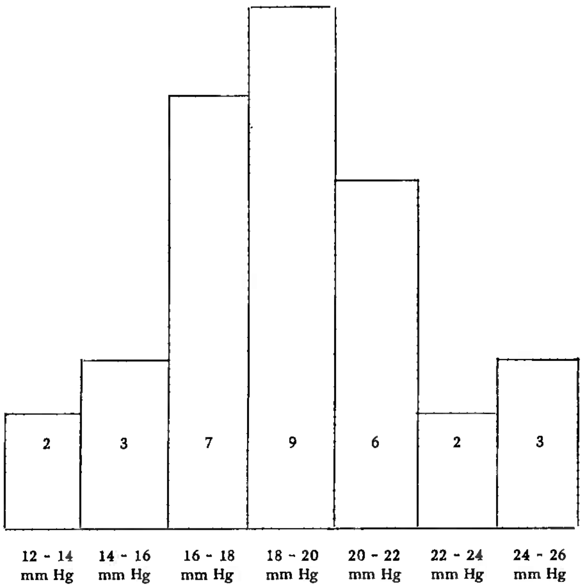

Figure 1.—Distribution of Baseline Intra-Ocular Pressures

In studying the group of volunteers, that is the mean intra-ocular pressure values throughout patrol, it is clear no consistent elevation of ocular tension occurs. In fact, during the period in which one would expect an uncompensated respiratory acidosis[1], the mean ocular tension steadily decreased. Following this, during what would correspond to the period of compensated respiratory acidosis, the mean value fluctuated within the normal range. It never exceeded the highest baseline value, however. This would lead us to believe that for the vast majority of submariners, the submerged environment presents no hazard to eyesight from an ocular tension rise.

Some corroboration of this could be derived from serially following the tonometry readings for submariners over a number of patrols. However, tonometry is not included in routine examinations often enough to allow retrospective tracing of trends from individual health records. Such is the case with the sixteen volunteers in this study. One can plot the number of Polaris patrols a submariner has made against his baseline intra-ocular pressure, as in Figure 3. This gives a guide, albeit a crude one, as to the presence or absence of a cumulative effect on ocular tension of repeated prolonged exposures to elevated carbon dioxide levels. The scattergram in Figure 3 demonstrates no tendency to cumulative displacement of ocular tension upward or downward with longer tenure on Polaris submarines. It must be realized that differing natural baseline values add a confusion factor to such a graph. Serially following a group of submarine personnel would be preferable, as already discussed, but is beyond the scope of this study.

The drop between the baseline tensions and those of patrol week four is significant at the .01 level, so sampling phenomena are not the cause.[10] The significance of the initial drop in ocular tension is somewhat obscure, and the effect is certainly contrary to the author's a priori expectations. Several possible reasons present themselves. The first

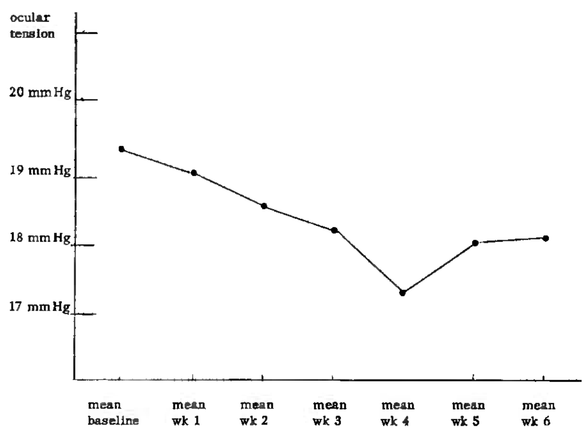

Figure 2—Mean Patrol Ocular Tensions

is that this is a result of random sampling of unchanged tensions, and not a true drop in ocular tension at all. This could be better explored by repeating the present study with

a larger group of volunteers. A second possibility is that reaction four on page 1 is in fact a reaction which contributes to aqueous formation. A third possibility is that some other factor, either an atmospheric constituent or a feature of life aboard FBM submarines, causes a decrease in ocular tension which overrides any effect of high carbon dioxide. The author cannot, on the basis of this study's design or results, make any definitive choice between these possibilities. Repeating the investigation to see if the results can be duplicated by other workers, may be helpful in reaching an answer.

When we scrutinize each volunteer we find only one who appears to have a consistent elevation of ocular tension while on patrol. This is B.W.M., whose family history of glaucoma has already been discussed. R.G., with a similar history, had no elevation while on patrol. This is far too small a sample from which to draw any firm conclusions regarding the safety of carbon dioxide rich atmospheres for those with a genetic substrate containing a glaucoma factor. However, B.W.M.'s ocular tension changes are enough to raise some doubt. A logical procedure would be to seek out similar individuals throughout the submarine force, and obtain comparative measurements ashore and while deployed.

CONCLUSIONS

In conclusion, there is one inference which can be drawn from the data presented, but three questions are raised. The inference is that exposure to the carbon dioxide levels common on Polaris submarines does not elevate the ocular tension in normal individuals. The questions raised are interrelated. Can the mean decrease in intra-ocular pressure during patrol be reproduced by other observers? What is the cause of this decrease, if indeed, the phenomenon can be confirmed? The third question, and the most pressing from an operational viewpoint, is whether a small population group, with a pre-disposition for glaucoma, is endangered by the submarine atmosphere.

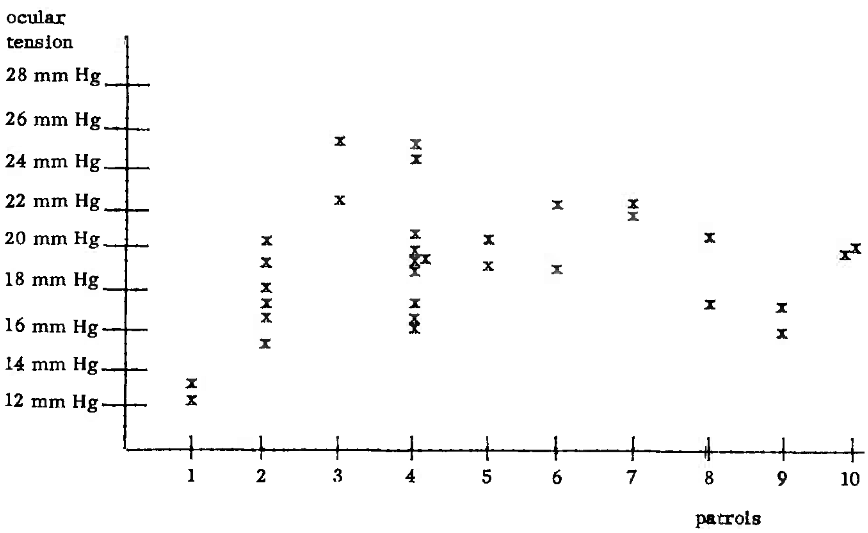

Figure 3—Number of Patrols vs Ocular Tension

The first and last of these questions can be answered by further careful observation along the lines of this study. To answer the second question will be more challenging, and perhaps ultimately more rewarding.

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13. ABSTRACT

This paper discusses the method of establishing that no hazard of increased intra-ocular pressure is incurred from the elevated carbon dioxide content of the sealed submarine atmosphere. The reasons for suspecting a possible intra-ocular pressure rise under such conditions are presented. The serial tonometry readings, both under control conditions and at elevated ambient carbon dioxide levels while on patrol are shown. The conclusion from this study is that no elevation of intra-ocular pressure accompanies physiologic adjustments to high carbon dioxide levels.

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